

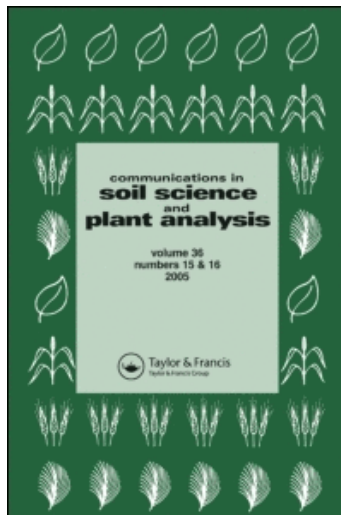
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### Effect of Manure Management on Carbon Evolution and Water Extractable Phosphorus

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## Effect of Manure Management on Carbon Evolution and Water Extractable Phosphorus

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### ABSTRACT

Soils with excessive phosphorus (P) levels due to manure application are an environmental concern because water extractable P (WEP) in runoff from these soils can contribute to increased amounts P in surface water, which can contribute to eutrophication of freshwater. Phosphorus based manure management is an option to reduce WEP and thereby reduce agricultural P runoff. In P based manure management, manure is applied to meet the P needs of a crop or not to exceed a given soil test level. Because P base manure management does not supply enough nitrogen (N) to meet the needs of the crop, addition fertilizer N needs to be applied. Fertilizer N applied to soils may increase the rate of mineralization of organic matter and lowers soil pH and therefore may affect the solubility of soil inorganic and organic P pools. The extent to

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which this may affect WEP or plant P availability is not known. Thus, laboratory and greenhouse studies were conducted to determine the effects of P based manure management on WEP and on short-term P plant availability. Phosphorus based manure management had no significant effect on the shift of organic P to WEP, but the increased acidity due to urea hydrolysis and subsequent nitrification of ammonia had a significant effect on the solubilization of P from the Ca-bound IP pool, thereby increasing WEP. This could be a significant consideration where Ca-bound IP dominates IP, P based manure management is implemented and increased WEP is subject to export to surface waters via runoff.

*Key Words:* Water quality; Eutrophication.

## INTRODUCTION

In the northeastern U.S., high rates of fertilizer and manure application have resulted in the majority of agricultural soils having excessive amounts of plant available phosphorus.<sup>[1,2]</sup> Soils with excessive P levels are an environmental rather than agronomic concern, as water extractable P (WEP) in runoff from these soils increases amounts of P in surface water, which can contribute to eutrophication of freshwater.<sup>[3,4]</sup> Water extractable P is generated when rain interacts with a thin layer of soil (0–5 cm) at the surface before becoming runoff.<sup>[5]</sup>

There are several options to reduce WEP and, thereby, diminish agricultural P export. Some of these options focus either on reducing total P inputs or use of manure and soil amendments to lower WEP.<sup>[6–9]</sup> One way to reduce total P inputs is the adoption of P based manure management in lieu of N based manure management. In N-based manure management, manure is applied to meet the N needs of the crop. Because the N:P ratio in manure is lower than in the crop, N based manure management leads to excessive soil P levels.<sup>[10]</sup> Indeed, a majority of soils recently tested in the northeast US (an area of intense animal agriculture) have a high or excessive soil P levels.<sup>[11]</sup> In P based manure management, manure is applied either to meet the P needs of a crop or not to exceed a given soil test level. Because P based manure management does not supply enough N to meet the needs of the crop, additional fertilizer N needs to be applied to meet the N needs of the crop.

Inorganic fertilizer N applied to soils can have a “priming” effect that increases the mineralization of organic N.<sup>[11]</sup> A P-based manure management utilizing N fertilizer may produce the ‘priming’ effect that increases the rate of organic P mineralization. The extent to which this may effect the



conversion of organic P to WEP or plant P availability is not known. Thus, the objective of this study is to determine the effects of N and P based manure management on WEP and short-term P plant availability.

## MATERIALS AND METHODS

The Ap horizons of a Hagerstown silt loam (Fine, mixed, mesic Typic Hapludalf) and a Watson silt loam (Fine-loamy, mixed, mesic Typic Fragiudult) were collected in central Pennsylvania, the Ap horizon of a Henlopen loamy sand (Sandy, siliceous, mesic Lamellic Paleudult) was collected in Delaware, the Ap horizon of an Othello silt loam (Fine-silty, mixed, mesic Typic Endoaquult) was collected on the Maryland Eastern Shore and the Ap horizon of a Georgia stony loam (Coarse-loamy, mixed, mesic Aquic Dystric Eutrochrept) was collected in western Vermont. All of these soils are important agricultural soils in their respective locations and had high to excessive levels of Mehlich III soil P due to a long history of manure application (Table 1). In preparation for the experiment, the soil samples were air dried and sieved (2.00 mm).

Dairy slurry was collected from a local dairy farm, homogenized in a laboratory blender and sampled for N and P analyses by the Pennsylvania State University Agriculture Analytical Services Laboratory (Table 2). Between collection and the start of the experiment, the dairy slurry was kept at 4°C in a sealed container.

One hundred twenty-gram aliquots of the five soils were treated with combinations of dairy slurry and/or urea to reflect three types of manure management: 1) nitrogen-based on crop requirement, 2) phosphorus-based on crop requirement, and 3) phosphorus-based on soil test P. In the nitrogen-based on crop requirement treatment (N Based-Crop), enough dairy slurry was added to supply 150 kg N ha<sup>-1</sup> to a corn silage crop,

**Table 1.** Some initial chemical properties of soils used.

Soil	pH	CEC (cmol kg <sup>-1</sup> )	P	K	Mg	Ca	Total N	Total C	C:N ratio
			(mg kg <sup>-1</sup> )				(g kg <sup>-1</sup> )		
Henlopen	5.2	4.4	296	78.0	48.0	260	0.475	6.95	14.6
Hagerstown	6.1	21.5	762	733	312	5260	2.30	22.0	9.57
Georgia	7.2	17.3	238	363	168	3160	2.58	27.2	10.5
Othello	5.6	13.1	464	316	192	1360	1.55	17.4	11.2
Watson	6.2	13.8	124	218	144	2000	1.78	18.0	10.1



**Table 2.** Summary of dairy slurry analyses and treatment loadings in each manure management treatment.

	Organic C	Total N	Ammonium N	Total P	C:N ratio
Concentration, mg kg <sup>-1</sup> dried slurry	9730	832	328	194	11.7
Treatment loading, mg kg <sup>-1</sup> soil					
Control	0	0	0	0	—
N Based-crop	1755	150	60	35	—
P Based-crop	878	113	105	18	—
P Based-soil	0	75	75	0	—

assuming that 50% of the N in the slurry would be available in the short term. In the phosphorus-based on crop removal treatment (P Based-Crop), enough slurry and urea were added to supply the same amount of N as the N-Crop management plus the equivalent of 35 kg P ha<sup>-1</sup>, the amount of P removed in a corn silage crop. In this treatment, N was supplied in almost equal amounts by the slurry (51%) and urea (49%). In the phosphorus-based on soil test (P Based-Soil) the same amount of N was supplied as urea-N only. Because all soils tested high or excessive in P, no additional phosphorus was required under this type of manure management, and no manure was applied. Each treatment was replicated four times, and there was an untreated check of each soil, also replicated four times. This resulted in a total of eighty experimental units.

For application to the soil, the slurry and urea treatment components were added to sufficient deionized water to wet each soil to field capacity.

The products were thoroughly mixed into the soil by placing it onto a fiberglass tray, pouring the materials and incorporating them with a metal spatula. After treatment, the soils were immediately placed into 0.95 L incubation chambers made from wide mouth glass canning jars with the lids fitted with four rubber septa. The septa were fixed into the lids with silicone cement.

The soils were incubated in the dark for 28 days at room temperature. During incubation, headspace gases were sampled at 1, 2, 3, 4, 7, 14, 21, and 28 days by removing 1 mL of headspace gas and storing the gas in evacuated glass containers until analysis. The samples were analyzed for CO<sub>2</sub> using a gas chromatograph equipped with a flame ionization detector (FID) and a nickel catalyst tube. After each sampling, the incubation chambers were unsealed, the air in the chamber flushed with ambient air, and the chambers resealed.



After incubation, the soils were removed from the chambers and air-dried. A one hundred gram aliquot of dry soil was taken for the greenhouse plant extraction experiment. The remaining twenty grams of soil was reserved for soil P fractionation.

The biologic extraction of P by wheat seedlings was accomplished using a modified Stanford–Dement procedure.<sup>[12]</sup> Wheat (*Triticum aestivum* L.) seedlings for the extraction were grown in 240-mL false-bottom plastic pots containing quartz sand. The plants were irrigated every other day with P and N-free Hoagland's solution.<sup>[13]</sup> About 15 seedlings per pot were grown for 16 d, at which time roots proliferated at the bottom of the pots.

Just prior to the start of the experiment the pots watered with an excessive amount of the P and N-free Hoagland's solution and allowed to drain. The false bottoms were removed and the roots placed in contact with 100 g of the air-dried, treated soil that was retrieved from the incubation chambers. There was sufficient moisture in the sand to wet the soil when the roots were placed in contact with it. The combined pots were weighed and this reference weight recorded. The pots were irrigated every day with the P and N-free Hoagland's solution to attain the reference weight.

The biologic extraction period lasted for 7 days. The experiment was blocked along the length of a greenhouse bench in four replications, and the soils and treatments were randomized within replications. The treatments were re-randomized within replications daily when the pots were irrigated.

Plant tops were harvested at a 1 cm stubble height, weighted, ground and analyzed for P and N. Total P concentration wheat tops, was determined using a modified semimicro-Kjeldahl procedure.<sup>[14]</sup> The procedure used a 1.113-g mixture of K<sub>2</sub>SO<sub>4</sub> and CuSO<sub>4</sub> (100:3 weight ratio), concentrated (18 M) H<sub>2</sub>SO<sub>4</sub> (4 mL) and 0.35 g of dried plant material. The mixture was digested at 180°C for 1 hr and 375°C for 2 hr. Phosphorus in the filtered and neutralized digests was determined by the molybdenum-blue method.<sup>[15]</sup>

Water extractable P was determined by shaking 1 g soil with 10 mL of distilled water for 5 min.<sup>[16]</sup> Phosphorus in the filtered and neutralized extracts was determined by the molybdenum-blue method.<sup>[15]</sup>

Soil was analyzed for soil Inorganic phosphorus, (IP) fractions according to the Hedley procedure.<sup>[17]</sup> The Hedley procedure involved sequential extraction of 0.5 g of soil with 1) a 2 cm<sup>2</sup> anion exchange resin membrane in 30 mL of 0.01 M CaCl<sub>2</sub>; 2) 30 mL of 0.5 M NaHCO<sub>3</sub> (pH 8.5); 3) 30 mL of 0.1 M NaOH; and 4) 30 mL of 1.0 M HCl each for 16 h.

After shaking the membrane square and soil (Step 1), the square was removed and rinsed free of adhering soil particles. Phosphorus retained on the membrane was removed by shaking the square end-over-end with 40 mL of 1 M HCl for 4 h. The membrane square was removed, rinsed with deionized



water, and shaken with an additional 40 mL of 1 *M* HCl for 4 h. Phosphorus in the HCl extracts was summed to give resin IP (biologically available).

Phosphorus in all filtered and neutralized extracts was determined by the molybdenum-blue method.<sup>[15]</sup> Phosphorus fractions determined in steps 2, 3, and 4 are subsequently referred to as bicarbonate IP (biologically available IP), hydroxide IP (amorphous and some crystalline Al and Fe phosphates), and acid IP (relatively stable Ca-bound P).

Organic P was determined by further subjecting the bicarbonate IP and acid IP fractions to a semi micro Kjeldahl digestion.<sup>[14]</sup> The phosphorus content of the Kjeldahl digests was measured by the colorimetric method of Murphy and Riley.<sup>[15]</sup> Organic phosphorus was then evaluated as the difference between the P contents of the digested bicarbonate acid IP fractions and the undigested bicarbonate and acid IP fractions.

All data were analyzed using the General Linear Model (GLM) procedure in SAS.<sup>[18]</sup> Least Square Means were separated using the pdiff option of the LSMEANS statement within the GLM procedure. All treatment differences discussed in the text are significant at the 0.05 level.

## RESULTS AND DISCUSSION

The amount of C evolved was significantly influenced by soils, manure management treatments and the resulting interaction (Table 3). Soils with the higher total C concentrations and higher pH levels tended to evolve more C. The Henlopen soil had the lowest total C levels and lowest pH and evolved significantly less C than the other soils. The soil that evolved the

**Table 3.** Least square means of C evolved from five soils incubated for 28 days.

	Control	N based-crop	P based-crop	P based-soil	
Soil	(mg C kg soil <sup>-1</sup> )				Mean
Henlopen	565	1190	888	665	827d*
Hagerstown	878	1266	1188	958	1072b
Georgia	988	1878	1377	886	1282a
Othello	612	1377	946	678	901c
Watson	945	1325	1266	994	1132b
Mean	798c	1405a	1133b	836c	

The soil by manure management interaction was significant ( $p < 0.05$ ).

\*Least square means in the same row or column followed by the same letter are not significantly different ( $p > 0.05$ ).

most C, the Georgia, had the highest total C level and highest pH. The Hagerstown and Watson had similar amounts of total C and pH levels and evolved similar amounts of C during the incubation. In contrast, the Watson and Othello soils had similar total C levels, but the Othello had a lower pH. Consequently, the Othello evolved significantly less C than the Watson.

Significantly more C was evolved from the N Based-Crop and P Based-Crop manure management treatments, in which manure was added, than in the other two treatments. The average apparent (manure management treatment minus Control) of C evolved in the N Base-crop ( $607 \text{ mg C kg soil}^{-1}$ ) and P Based-Crop ( $335 \text{ mg C kg soil}^{-1}$ ) amounted to about 35 and 38% of the applied manure C for the two treatments, respectively. Although the overall means for the P Based-Soil treatment was not significantly different from that of the Control, somewhat (5 to 15%) more C was evolved from the P Based-Soil treatment than from the Control in four of the five soils. In addition to organic matter decomposition, a portion of the C evolved during the incubation could be derived from urea hydrolysis. Carbon via urea application in the P Based-Soil treatment ( $32 \text{ mg kg soil}^{-1}$ ) accounted for 30 to 65% of the apparent C evolved in the P Based-Soil treatment (with the exception of the Georgia soil).

There was a significant soil by treatment interaction in the amount of C evolved (Table 3). The interaction was due to significant differences among soils in the apparent amount (N Based-Crop minus Control) of C evolved within the N Based-Crop treatment. In this treatment for example, the apparent amount of C evolved ranged from  $388 \text{ mg C kg soil}^{-1}$  (a 19% increase over Control) for the Hagerstown soil to  $890 \text{ mg C kg soil}^{-1}$  (a 51% increase over Control) for the Georgia soil. In contrast apparent C evolved had a narrow range of  $310 \text{ mg C kg soil}^{-1}$  in the Hagerstown soil to  $389 \text{ mg C kg soil}^{-1}$  in the Georgia soil.

Averaged over soils, dairy slurry application increased WEP by 2.0 and  $1.2 \text{ mg kg soil}^{-1}$  for the N Based-Crop and P Based-Soil treatments, respectively (Table 4). Also, averaged over soils the P Based-Soil manure management treatment had no significant effect on WEP. There was however a significant soil by manure management treatment interaction due in large part to increased WEP levels in the P Based-Soil manure management treatment of the Hagerstown soil.

Time difference in the amount of C evolved between P Based-Soil manure management treatment and the Control was not significant ( $P > 0.05$ ), the increased amount of WEP in the P Based-Soil on the Hagerstown soil cannot be attributed to P being solubilized from the organic P fraction. This is supported by the fact that there was no significant manure management treatment effect on organic P. Rather a more plausible explanation for the increased WEP in the P Based-Soil





**Table 4.** Least square means of water extractable P (WEP) after 28 day incubation.

	Control	N based-crop	P based-crop	P based-soil	
Soil	(mg P kg soil <sup>-1</sup> )				Mean
Henlopen	11.5	14.8	11.8	10.8	12.2c*
Hagerstown	32.8	35.0	35.2	34.1	34.3a
Georgia	12.4	13.0	12.3	11.3	12.2c
Othello	24.5	28.3	27.6	25.0	26.4b
Watson	4.2	4.1	4.2	4.7	4.32d
Mean	17.1c	19.1a	18.3b	17.2c	

The soil by manure management interaction is significant ( $p < 0.05$ ).

\*Least square means in the same row or column followed by the same letter are not significantly different ( $p > 0.05$ ).

treatment of the Hagerstown soil is P being solubilized from the very large HCl extractable (Ca bound) IP fraction by the increased acidity caused by urea hydrolysis and subsequent nitrification of ammonia (Table 5). The HCl extractable IP fraction is at least eight times greater than that of the other soils, and at a soil pH 6.2 (Table 1) the Ca bound IP should largely be mono or dicalcium phosphate and thus be readily solubilized by increased acidity caused by urea hydrolysis. In relation to the other soils, the Hagerstown soil had a longer history of manure application as evidenced by the initial high levels of P in the soil (Table 1). In soils receiving high amounts of manure, IP is shifted from Al and Fe bound IP pools to the Ca-bound IP pools due to Ca additions in the manure.<sup>[19]</sup>

**Table 5.** Summary of Headley inorganic P fractions and organic P of control after incubation.

	Strip	NaHCO <sub>3</sub>	NaOH	HCl	
Soil	(mg P kg soil <sup>-1</sup> )				Organic
Henlopen	66d*	33c	134d	30c	33b
Hagerstown	305a	277a	525a	2111a	107a
Georgia	101c	73b	333b	262b	105a
Othello	145b	100b	324b	128c	109a
Watson	98c	42c	306c	73c	86a

\*Means in the same column followed by the same letter are not significantly different ( $p > 0.05$ ).



The dry matter (DM) yield of the wheat seedlings was significantly affected by soils and the soils by manure management treatment interaction, but not by the manure management treatment alone (Table 6). The soils by manure management interaction was caused by DM yield increasing steadily on the Hagerstown soil with increasing fertilizer N in the manure management treatments and changing erratically in the other soils with increasing fertilizer N in the manure management treatments. Dry matter yields were correlated with both plant P uptake ( $r = 0.876$ ) and plant N uptake ( $r = 0.895$ ).

Plant P uptake was significantly affected by soils, manure management treatment and the resulting soil by manure management treatment interaction (Table 6). This interaction was the result of plant P uptake increasing in the Hagerstown with increasing amount of fertilizer N in the three manure management treatments and not to increasing or declining in the other soils. The increase in WEP (Table 4) due to increased solubility of the large reserve of Ca bound IP in the P Based-Soil manure management treatment in the Hagerstown soil was probably the cause of the interaction. Indeed, plant P uptake was significantly correlated with WEP ( $r = 0.704$ ,  $p < 0.05$ ).

**Table 6.** Least square means of dry matter (DM) yields and, plant P uptake, from five soils subjected to different manure management treatments.

Soil	Control	N based-crop	P based-crop	P based-soil	Mean
DM yield, mg pot <sup>-1</sup>					
Henlopen	412	445	465	438	440e*
Hagerstown	765	610	725	730	708a
Georgia	493	535	510	568	526d
Othello	640	678	675	650	661b
Watson	608	625	588	658	619c
Mean	584a	579a	593a	609a	
Plant P uptake, mg pot <sup>-1</sup>					
Henlopen	2.99	3.82	3.69	3.57	3.52d
Hagerstown	7.60	5.60	6.70	8.43	7.08a
Georgia	4.52	4.82	4.63	5.23	4.80c
Othello	5.27	5.44	5.62	5.15	5.37b
Watson	4.49	4.73	4.42	4.53	4.55c
Mean	4.97b	4.88b	5.01b	5.38a	

The soil by manure management interaction significant for DM yield and plant P uptake ( $p < 0.05$ ).

\*Least square means in the same row or column followed by the same letter are not significantly different ( $p < 0.05$ ).



In contrast to the correlation of plant P uptake with WEP, correlation of plant P uptake with organic P was only  $r = 0.356$ . Although this lower correlation is significant, it does indicate that the effect of the manure management treatments on soil organic P and the subsequent effects on WEP and plant P uptake, within the time frame of the experiment, may not be as important as those on the solubilization of the Ca-bound IP fraction under some soil conditions.

The implication that P Based-Soil manure management may increase the solubility of soil Ca-bound IP indicates that careful attention should be paid to soil pH when this type of manure management is being implemented to reduce soil P runoff from cropland. Continuing use of N fertilizers in P Based-Crop manure management will lower soil pH and increase the solubility of relatively insoluble Ca phosphates formed at higher soil pH levels<sup>[20]</sup> and may increase the potential for WEP to be subject to export via runoff. Maintaining soil pH at the upper end of the desired range for the crop grown will minimize the solubilization of Ca-bound IP.

## CONCLUSIONS

The effect of manure management on C evolution was almost entirely due to the addition of C in manure rather than from soil organic matter. Also, urea applied in the P based manure management treatments apparently had no effect on the transfers of P from organic P to WEP that could be attributed to the ‘priming’ effect. However, the increased acidity due to urea hydrolysis and subsequent nitrification of ammonia in the P Based-Soil manure management treatment may have a significant effect on the solubilization of P from the Ca-bound IP pool, thereby increasing WEP. This could be a significant consideration where Ca-bound IP dominates IP, a P Based-Soil manure management is implemented and increased WEP is subject to export to surface waters via surface runoff. However, this needs to be evaluated in different soils and under field conditions.

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